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ALIEN ANNUAL GRASSES AND FIRE IN THE MOJAVE DESERT

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ABSTRACT

Fires have become more frequent in the Mojave Desert since the 1970's, threatening native plants and animals. This study describes how different annual plants facilitate the spread of fire during summer when weather conditions are optimal for fire. Eight annual plant taxa were evaluated: the alien grasses *Bromus* (*B. madritensis* L. subsp. *rubens* (L.) Husnot, *B. tectorum* L., *B. trinii* Desv.) and *Schismus* (*S. arabicus* Nees, *S. barbatus* (L.) Thell.), the alien forb *Erodium cicutarium* (L.) L'Hér, the native grass *Vulpia* (*V. microstachys* (Nutt.) Munro, *V. octoflora* (Walter) Rydb.), the native forbs *Amsinckia tessellata* A. Gray, *Descurainia pinnata* (Walter) Britton, and *Phacelia tanacetifolia* Benth., and other native forbs (119 species combined). Frequency and cover of dead annual plants were measured to describe the composition of fine fuels in summer (7 to 14 July), and compared to measurements of live annual plants in spring (12 April to 11 May) to determine their persistence as fuels after they senesced (summer : spring ratio). These data were collected during 1995 at 34 sites in the central, southern, and western Mojave Desert. Also described were the effects of each annual plant group in facilitating the spread of three 2.25 ha experimental fires conducted in August, 1995.

Absolute frequency and cover and summer : spring ratios were highest for *Bromus* and *Schismus,* and lowest for native forbs. Alien annual grasses contributed most to the continuity and amount of dead annual plants and to the spread of summer fires. Fire spread rapidly (12 m/min) and continuously across interspaces with *Bromus* and slowly (1 m/min) and discontinuously with *Schismus*. No other annual plant group produced sufficient continuous biomass to carry fire across interspaces. Fire management must include the control of alien annual grasses in the Mojave Desert.

The frequency of fire, the number of fires caused by humans (Fish and Wildlife Service 1994; Brooks 1998a), and the dominance of alien annual grasses (Hunter 1991; Brooks 1998b; Kemp and Brooks 1998) all increased between the 1970's and 1990's in the Mojave Desert. Fires caused by humans are most common near urban developments, major roads, and where off-highway vehicle use is unlimited (United States Department of the Interior records), whereas fires caused by lightening are typical of more remote wilderness areas. Alien annual grasses dominate all of these areas, and biomass of one species in particular, *Bromus madritensis* L. subsp. *rubens* (L.) Husnot, is strongly correlated with size and frequency of fire (Brooks 1998b). Abundance of alien annual grasses is also positively correlated with the frequency of fire in the Sonoran Desert (Brown and Minnich 1986; Schmid and Rogers 1988). Thus, dominance of alien annual grasses appears to be a primary environmental correlate of fire in the Mojave Desert.

Areas dominated by alien annual grasses often have lower biomass and diversity of native forbs (Brooks 1998b; Brooks and Berry 1999), but it is unclear why landscapes dominated by them are more flammable than those dominated by native forbs in the Mojave Desert. Possible reasons include the higher surface to volume ratio of grasses compared to forbs that makes them easier to ignite (Kauffman and Uhl 1990), the more continuous cover of fuel that annual grasses often create on the landscape (Pyne et al. 1996), and the apparent ability of alien annual grasses to remain rooted and upright longer than native forbs allowing them to persist as flammable fuels into the summer when the threat of fire is highest (Brooks and Berry 1999).

Widely spaced shrubs and bunchgrasses with relatively bare interspaces between them characterize native Mojave Desert plant communities (Rundel and Gibson 1996). Frequent breaks in the continuity of fine fuels hinder the spread of fire, which is a primary reason fire is considered to be historically uncommon in this region (Humphrey 1974; O'Leary and Minnich 1981; Brown and Minnich 1986). The ability of alien annual grasses to produce high amounts of persistent flammable fuels in perennial plant interspaces seems to promote Mojave Desert fires (Brooks 1998b).

The purpose of this study was to compare the roles of alien annual grasses and other annual plants in facilitating the spread of fire in the Mojave Desert. This was accomplished by measuring the frequency and cover of fine fuels produced by different annual plant species and describing how flames spread through these fuels during experimental summer fires. Frequency was measured to evaluate the continuity and cover was measured to evaluate the amount of annual plant fuels. The summer : spring ratios of frequency and cover were calculat-

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ed to determine the amount that each decreased between spring and summer. Absolute frequency and cover during summer were measured to compare the characteristics of annual plant fuels during the time of year when high temperatures, low relative humidity, and low fuel moisture levels create conditions that are ideal for fire.

Methods

Eight annual plant taxa were analyzed: *Bromus* [*B. madritensis* subsp. *rubens, B. tectorum* L., *B. trinii* Desv.], *Schismus* (*S. arabicus* Ness, *S. barbatus* [L.] Thell.), *Erodium cicutarium* (L.) L'Hér, *Vulpia* (*V. microstachys* [Nutt.] Munro, *V. octoflora* [Walter] Rydb.), *Amsinckia tessellata* A. Gray, *Descurainia pinnata* (Walter) Britton, *Phacelia tanacetifolia* Benth., and other natives (119 forb species, Brooks 1998b Appendix 3.1). The first two are alien grasses, the third is an alien forb, the fourth is a native grass, and the remaining species are native forbs. These taxa are among the most widespread and abundant annual plants in the central, southern, and western Mojave Desert (Brooks 1998b). The one exception is *Vulpia,* which was included because of its possible ecological similarities with the alien annual grasses. Some species were grouped and analyzed as genera because they could not be reliably distinguished during the summer. Plant nomenclature followed Hickman (1993).

Frequency and cover of annual plants. Frequency and cover of annual plants were measured at each of 34 sites located in the central (n = 16), southern (n = 8), and western (n = 10) Mojave Desert (Fig. 1). Sites were chosen by randomly selecting half the townships located within each of the three regions and randomly selecting one of the 1 mi^2 sections within each township from those that did not contain playas, mountaintops, or private lands. Final sites were located within each section adjacent to but greater than 50 m from dirt roads and greater than 2 km from paved roads and human habitations.

A single 360 m transect with twenty-five sampling points placed 15 m apart was established at each of the study sites. The transect was oriented parallel to the elevational contour to sample alternating run-off and run-on microtopographic positions. At each site twenty-five replicate measurements were made within two microhabitats, beneath the north side of perennial plant canopies (>50 cm dia.) and in the interspace between them (>1 m from perennial plant canopies). Within each microhabitat cover and frequency were estimated using a 22 cm long point-frame of ten equally spaced 1.5 mm diameter pins (Greig-Smith 1964). The frame was oriented perpendicular to the ground, each pin was lowered to the surface of the soil, and the number of times each pin touched above-ground parts of annual plant species was recorded. Frequency was estimated as the proportion of the pins in each frame that touched at least one plant part and cover was estimated as the total number of pin touches per 10-pin frame. More detailed site and sampling design descriptions were presented by Brooks (1998b).

Data were obtained during spring and summer 1995 following a winter with 200% of average rainfall (National Oceanographic and Atmospheric Administration 1995). Measurements were first made from 12 April through 11 May when most species had reached peak biomass and just before they began to senesce. Only living plant material was measured. The second measurements were made from 7 through 14 July, when all germinated annual plants were dead. Because spring measurements were followed by biomass clipping (Brooks 1998b), summer measurements were recorded 20 cm from the spring measurements. Dead annual plant material included some senescent biomass from previous years in addition to plants that grew during the spring. Only material that was alive in spring 1995 was used to calculate the summer: spring ratios. Annuals that were alive in spring could be identified in summer because they were golden brown and often contained inflorescences and leaves. Annuals still standing after one year typically acquire a gray hue and lose their inflorescences and leaves.

Average frequency and cover of the eight annual plant taxa from each site were used as replicates to calculate average values across the entire study region (n = 34 replicates). Sites that did not possess at least one point-frame hit for a given plant taxa during the spring were not used in the estimate of summer: spring ratios. Some of the less common species (e.g., *P. tanacetifolia*) were not detected at some sites, reducing the number of replicates for this group. Hence, sample sizes varied among groups and differences among them were tested using Tukey's studentized range test that is robust for unequal sample sizes ($P \leq 0.05$) (Sokal and Rohlf 1995). Arcsine transformations were performed on ratios and square root transformations were performed on absolute counts prior to testing.

Experimental fires. To evaluate the role of different annual plants in facilitating the spread of fire, detailed observations were made during three experimental fires in the western (35°14′30″N, 117°51′15″W), central (35°07′30″N, 117°07′45″W), and southern (34°41′30″N, 117°57′30″W) Mojave Desert (Fig. 1). These fires were conducted on 16, 22, and 24 August 1995 respectively. Each site was 150 × 150 m (2.25 ha) and dominated by *Bromus* spp. and/or *Schismus* spp. Dead annual plants were ignited using a continuous flame line applied with a drip-torch (diesel/unleaded gas mix) along the upwind border of each site.

The total amount of annual plant fuels (nearest dry 25 kg/ha) and the dominant annual plant species in the beneath-canopy and interspace micro-

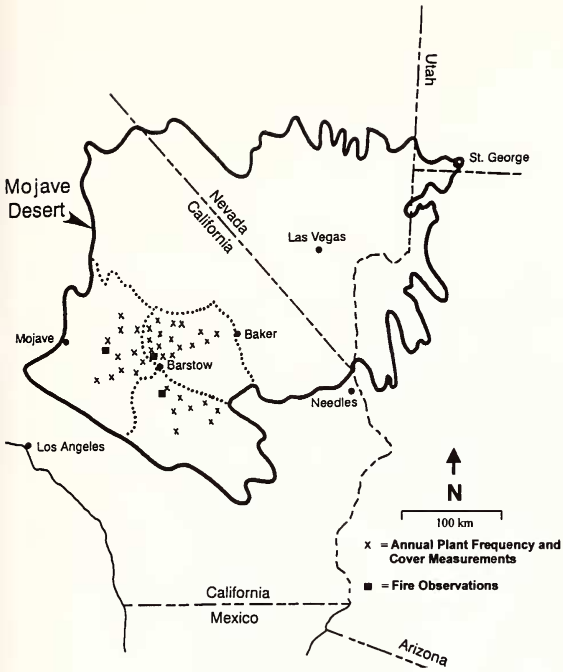

FIG. 1. Locations of the 34 study sites in the central, southern, and western regions of the Mojave Desert.

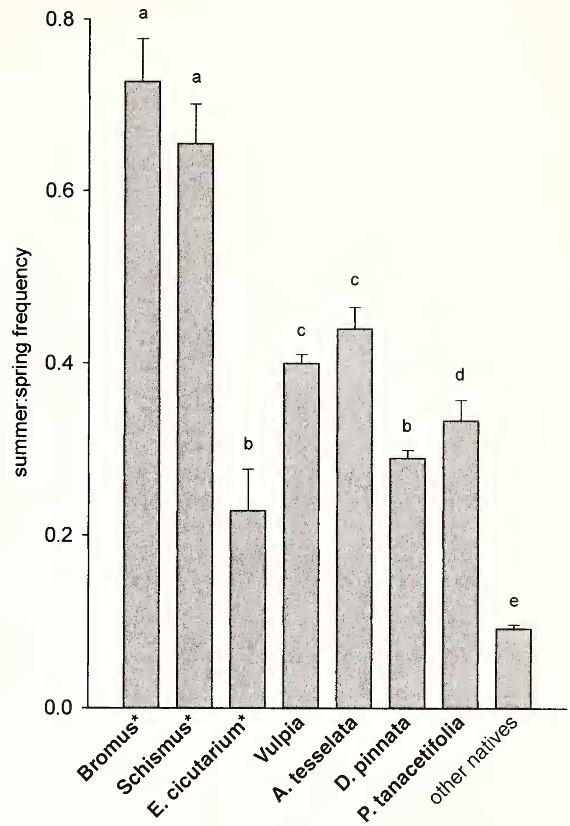

FIG. 2. Summer : spring frequency of annual plants averaged over 34 sites in 1995 (+1 SE). Dissimilar letters indicate significant differences using Tukey's studentized range test ($P < 0.05$). * alien species.

habitats were determined using visual estimation. These estimates were based on the author's experience physically sampling annual plant biomass and visually estimating cover in the Mojave Desert. Rates of fire spread and flame lengths were recorded at 15 random interspace points during each fire. The total amount of burned area (nearest 25%) and continuity of burning were visually estimated after each fire. Air temperature, relative humidity, cloud cover, wind speed and direction, at the beginning and end of each fire were recorded, because weather conditions can affect fire behavior.

RESULTS

Frequency and cover of annual plants. The proportion of point frame hits for *Bromus* spp. was 90% *B. madritensis* subsp. *rubens* and 10% *B. tectorum* and *B. trinii* combined during spring 1995. The proportion of *Schismus* spp. species were not estimated because *S. arabicus* and *S. barbatus* could not be reliably distinguished in the field. The proportion of *Vulpia* species was 60% *V. octoflora* and 40% *V. microstachys.* Estimates of total annual plant cover were highly correlated with concurrent measurements of above-ground live biomass during spring 1995 (Brooks 1998b, $r = 0.64$).

Summer : spring frequency was highest for *Bromus* spp. and *Schismus* spp. and lowest for the other natives category (Fig. 2). *Vulpia* spp., *A. tessellata, D. pinnata,* and *P. tanacetifolia* had intermediate frequency ratios, but very low absolute frequencies (Fig. 3). *Erodium cicutarium* had an intermediate frequency ratio and absolute frequency. The combination of high summer : spring frequencies and high absolute frequencies during summer indicate that *Bromus* spp. and *Schismus* spp. contributed most to the frequency of dead annual plants in the summer.

Summer : spring cover was highest for *Bromus* spp. and lowest for the other natives category (Fig. 4). *Schismus* spp., *A. tessellata, D. pinnata,* and *P. tanacetifolia* had intermediate ratios, but absolute cover of *Schismus* was significantly higher than all groups except *Bromus* spp. ($P < 0.05$, Fig. 5). Summer : spring and absolute cover were relatively low for *E. cicutarium.* Similar to the frequency results, the combination of high summer : spring cover ratios and high absolute cover during summer indicate that *Bromus* spp. and *Schismus* spp. contributed most to the cover of dead annual plants in the summer.

Experimental fires. The central Mojave site had the lowest amount of fine fuels (Table 1) and the lowest wind speed and highest relative humidity during the fire (Table 2). As a result, fire did not spread beyond ignition points.

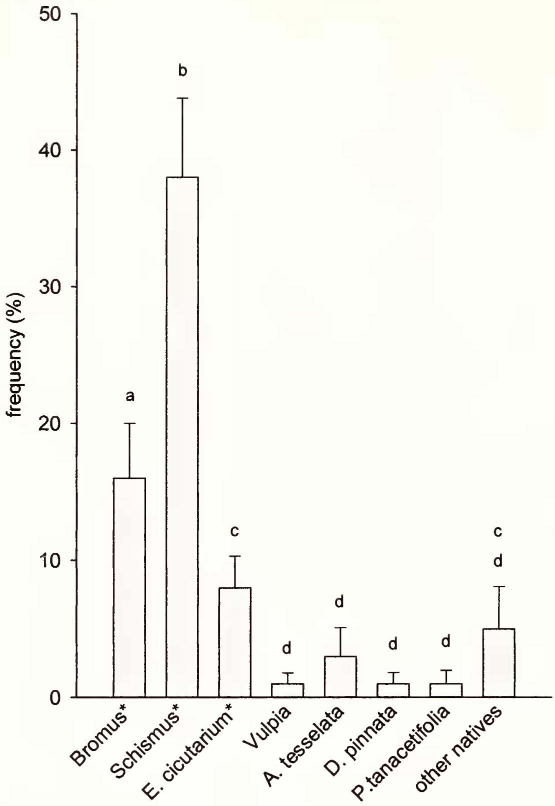

FIG. 3. Absolute frequency of annual plants averaged over 34 sites in 1995 (+1 SE). Dissimilar letters indicate significant differences using Tukey's studentized range test (P < 0.05). * alien species.

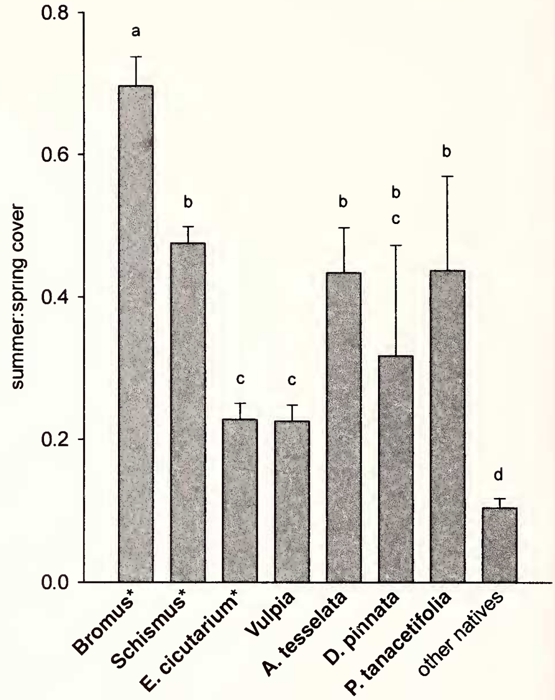

FIG. 4. Summer:spring cover of annual plants averaged over 34 sites in 1995 (+1 SE). Dissimilar letters indicate significant differences using Tukey's studentized range test (P < 0.05). * alien species.

The southern Mojave site had relatively high amounts of fine fuels in the beneath-canopy and interspace microhabitats (Table 1). Relative humidity was relatively low and wind speeds were moderate, so fire spread relatively fast across interspaces and 50% of the site burned over large continuous areas (Table 2).

The western Mojave site had high amounts of fine fuels in the beneath-canopy microhabitat, but only moderate amounts in the interspaces (Table 1). Relative humidity was relatively low and wind speeds were high (Table 2), but fire spread relatively slow and 50% of the total site burned in many small patches.

Low humidity, moderate to high wind speeds, and substantial interspace biomass of fine fuels comprised mostly of alien annual grasses were associated with high rates and continuities of fire spread. In contrast, relatively high humidity, low wind speeds, and virtually no fine fuels between shrubs were associated with no fire spread. Differences in fire behavior were not attributed exclusively to weather or fuel composition, because these variables were confounded. However, fires were always fueled by the dead stems of alien annual grasses.

Fire spread was extensive and rapid where *Bromus* spp. was codominant with *Schismus* spp. in interspaces (southern Mojave site; Table 1). Fire spread was patchy and slow where only *Schismus* spp. was dominant in interspaces (western Mojave site). Average wind speed during the fire at the western Mojave site was twice that at the southern Mojave site (Table 2), yet fire spread faster and more continuously across the latter site (Table 1). Thus, high interspace biomass of *Bromus* spp. and *Schismus* spp. resulted in greater fire danger at the southern Mojave site, even though wind speeds were much higher at the western Mojave site.

Where *Bromus* spp. was abundant in interspaces fire spread approximately 12 m/min with flame lengths up to 30 cm. The heat generated by *Bromus* spp. was sufficient to ignite and consume dead stems of native forbs and plant litter. *Schismus* spp. was also effective at carrying fire across interspaces, but only at 1 m/min with flame lengths 5–10 cm. Flame lengths from *Schismus* spp. could not easily be seen and often only burned the top 25% of *Schismus* spp. stems, indicating that temperatures were relatively low. Most dead native forb stems and litter material were unburned. Although *Bromus* spp. and *Schismus* spp. both facilitated the spread of fire, only *Bromus* spp. produced long

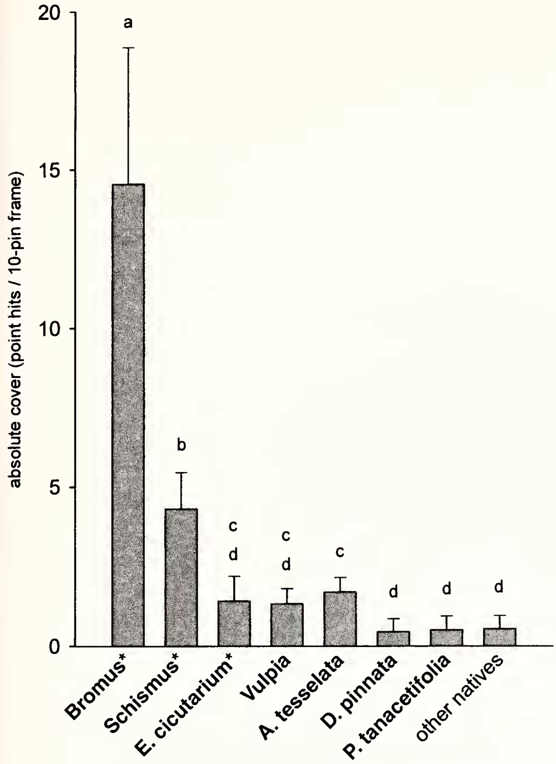

FIG. 5. Absolute cover of annual plants averaged over 34 sites in 1995 (+1 SE). Dissimilar letters indicate significant differences using Tukey's studentized range test ($P < 0.05$). * alien species.

flame lengths that consumed considerable amounts of annual plant biomass. *Erodium cicutarium* and native annuals did not contribute significantly to the spread of fire, because of low frequency and cover.

Flames fueled by *Bromus* spp. were sufficient to consume small shrubs such as *Ambrosia dumosa* (A. Gray) Payne, *Krascheninnikovia lanata* (Pursh) A. D. J. Meeuse & Smit, *Hymenoclea salsola* A. Gray, and *Lycium andersonii* A. Gray, whereas flames fueled by *Schismus* spp. were rarely hot enough to ignite these shrubs. Fire intensity in *Bromus* spp. was usually insufficient to ignite large shrubs such as *Larrea tridentata* (DC.) Cov. However, *Larrea tridentata* containing large accumulations of *Bromus* spp. stems and dead shrub stems in the sub-canopy were highly susceptible to burning. In these cases fire carried from *Bromus* spp. stems, to dead shrub stems, to live shrub stems, and typically resulted in the entire shrub being consumed by flames.

DISCUSSION

The alien annual grasses *Bromus* spp. and *Schismus* spp. appear to be necessary for fire to spread across the Mojave Desert landscape. These were the only annual plant taxa that produced abundant and continuous cover of fine fuels that persisted into the summer fire season.

Intermediate fuels produced by large forbs can add to the continuity and amount of flammable biomass, although fine fuels produced by alien annual grasses are generally required to sustain a fire (Brooks personal observation). These large forbs include the alien mustards *Brassica tournefortii* Gouan, *Hirschfeldia incana* (L.) Lagr.-Fossat, *Sisymbrium altissimum* L., *Sisymbrium irio* L., and *Descurainia sophia* (L.) Webb, and the weedy native *A. tessellata.* They are especially common along roads where fires frequently start and some of the alien species are rapidly expanding their range and becoming established away from roads in the Mojave and Colorado deserts (Kemp and Brooks 1998; Brooks and Berry 1999). Hence, large weedy forbs may present a more widespread fire hazard in the future.

Thick layers of annual plant litter often develop where alien annual grasses are abundant (Brooks and Berry 1999). Accumulations of litter led to particularly hot temperatures, long flame residency times, and continuous burn patterns in experimental fires conducted during summer 1995 and 1996 in the Mojave Desert (Brooks unpublished). Plant litter decomposes slowly in desert regions and grasses can be among the slowest (Facelli and Pickett 1991). Thus, litter accumulation may be another mechanism by which alien annual grasses facilitate the spread of Mojave Desert fires.

The current study suggests that *Bromus* spp. fuel fast moving hot fires whereas *Schismus* spp. fuel slower moving cooler fires. This pattern is gener-

TABLE 1. SITE DATA FOR EXPERIMENTAL FIRES CONDUCTED IN AUGUST 1995.

Site	Fine fuels (kg/ha)		Dominant annuals (spp. >25% relative cover)		Interspace fire spread (m/min) (1 SE)	Area burned (% of 2.25 ha)
	Beneath-canopy	Inter-space	Beneath-canopy	Interspace		
Central Mojave	300	25	*Bromus/Schismus*	*Schismus*	0 (0)	0
Southern Mojave	700	200	*Bromus*	*Bromus/Schismus*	12 (8)	50 (continuous)
Western Mojave	800	100	*Bromus/Schismus*	*Schismus*	1 (1)	50 (patchy)

TABLE 2. WEATHER DATA FOR EXPERIMENTAL FIRES CONDUCTED IN AUGUST 1995.

Site		Time (PST)	Air temperature (°C)	Rel. humidity (%)	Cloud cover (%)	Wind direction	Wind speed (km/h) (gusts)
Central Mojave	begin	1030	35	32	0	SSW	0 (8)
	end	1115	41	25	0	SSW	0 (8)
Southern Mojave	begin	1020	33	17	0	SSE	5 (5)
	end	1130	35	15	0	SSE	8 (13)
Western Mojave	begin	1130	37	19	0	NNE	16 (18–32)
	end	1215	38	10	0	NNE	16 (18–32)

ally consistent among seasons and years (Brooks personal observation). The immediate ecological effects of *Bromus* spp. fires are probably more significant, because they are more intense and often consume perennial shrubs. However, *Schismus* spp. can facilitate the spread of fire between patches of *Bromus* spp., and promote fires at arid low elevation sites where *Bromus* spp. are less abundant (Brooks 1998b). During the 1990's in the Mojave Desert some fires fueled mostly by *Schismus* spp. exceeded 40 ha (100 acres) before they were extinguished by fire crews (United States Department of the Interior records).

High postfire dominance of alien annual grasses can promote subsequent fires in the Great Basin desert (Whisenant 1990; Peters and Bunting 1994; Billings 1994) and other ecosystems (D'Antonio and Vitousek 1992). Post-fire plant communities in the Mojave and Sonoran deserts are also typically dominated by alien annual grasses (O'Leary and Minnich 1981; Brown and Minnich 1986; Brooks unpublished), so previously burned areas appear to be more susceptible to fire than unburned areas. This grass/fire cycle is a significant ecological threat because most native plant species are poorly adapted to survive fire in the deserts of southwestern North America (Tratz 1978; O'Leary and Minnich 1981; Wright and Bailey 1982; Brown and Minnich 1986; Billings 1994; Lovich and Bainbridge 1999).

Drought years may reduce the dominance of *Bromus* spp. in both recently burned and unburned areas decreasing the chance of fire (Minnich personal communication), but these effects vary among sites. For example, the winter of 1998–1999 was very dry in the Mojave Desert and most *Bromus* spp. seedlings did not survive to maturity on low elevation bajadas, whereas many survived and reproduced on high elevation hills and mountains (Brooks personal observation). High elevation sites may provide more mesic conditions that allow *Bromus* spp. to survive drought better than at lower elevations. Recurrent fire is most prevalent at these high elevation sites (Brooks unpublished) where high biomass of alien annual grasses and the physical effects of steep slopes promote fire. Establishment of the grass/fire cycle appears to be more likely on high elevation slopes than on low elevation bajadas.

Management of fire in the Mojave Desert should focus on minimizing the dominance of alien annual grasses and preventing the establishment of new plant species that can increase landscape flammability (Brooks and Berry 1999). Such species include large forbs and the perennial bufflegrass (*Pennisetum ciliare,* Brooks et al. 1999). Sources of ignition from human activities should also be minimized, especially where alien annual grasses are abundant and topography is conducive to the spread of fire.

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LITERATURE CITED

BILLINGS, W. D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. Pp. 22–31 *in* S. B. Monsen and S. G. Kitchen (eds.). Proceedings—Ecology and Management of Annual Rangelands, 18–22 May 1992, Boise ID. General Technical Report INT-GTR-313, Department of Agriculture, Forest Service, Intermountain Research Station.

BROOKS, M. L. 1998a. Effects of fire on the desert tortoise, *Gopherus agassizii.* International Conference on Turtles and Tortoises, 30 July–2 August 1998, Northridge, CA.

———. 1998b. Ecology of a biological invasion: Alien annual plants in the Mojave Desert. Ph.D. dissertation, University of California, Riverside, CA.

BROOKS, M. L. AND K. H. BERRY. 1999. Ecology and Management of Alien Annual Plants in the California Deserts. California Exotic Pest Plant Council Newsletter (in press).

BROOKS, M. L., T. C. ESQUE, AND C. R. SCHWALBE. 1999. Effects of exotic grasses via wildfire on desert tortoises and their habitat. Desert Tortoise Council Symposium, 5–8 March 1999, St. George, UT.

BROWN, D. E. AND R. A. MINNICH. 1986. Fire and creosote bush scrub of the western Sonoran Desert, California. American Midland Naturalist 116:411–422.

D'ANTONIO, C. M. AND P. M. VITOUSEK. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 3:63–87.

FACELLI, J. AND S. T. A. PICKETT. 1991. Plant litter: its dynamics and effects on plant community structure. Botanical Review 57:1–31.

FISH AND WILDLIFE SERVICE. 1994. Desert Tortoise (Mojave Population) Recovery Plan. United States Fish and Wildlife Service, Portland, OR.

GREIG-SMITH, P. 1964. Quantitative Plant Ecology, 2nd ed. Butterworth, London.

HICKMAN, J. C. (ED.) 1993. The Jepson Manual: Higher Plants of California. University of California Press, Berkeley, CA.

HUMPHREY, R. R. 1974. Fire in deserts and desert grassland of North America. Pp. 365–401 *in* T. T. Kozlowski and C. E. Ahlgren (eds.). Fire and Ecosystems. Academic Press, New York.

HUNTER, R. 1991. *Bromus* invasions on the Nevada Test Site: present status of *B. rubens* and *B. tectorum* with notes on their relationship to disturbance and altitude. Great Basin Naturalist 51:176–182.

KAUFMAN, J. B. AND C. UHL. 1990. Interactions of anthropogenic activities, fire, and rain forests in the Amazon basin. Pp. 117–134 *in* J. G. Goldammer (ed.). Fire in the Tropical Biota: Ecosystem Processes and Global Challenges. Springer-Verlag, Berlin.

KEMP, P. R. AND M. L. BROOKS. 1998. Exotic Species of California Deserts. Fremontia 26:30–34.

LOVICH, J. E. AND D. BAINBRIDGE. 1999. Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration. Environmental Management (in press).

NATIONAL OCEANOGRAPHIC AND ATMOSPHERIC ADMINISTRATION. 1995. Climatological data annual summary, National Oceanographic and Atmospheric Association: 99.

O'LEARY, J. F. AND R. A. MINNICH. 1981. Postfire recovery of creosote bush scrub vegetation in the Western Colorado Desert. Madroño 28:61–66.

PETERS, E. F. AND S. C. BUNTING. 1994. Fire conditions pre- and postoccurence of annual grasses on the snake river plain. Pp. 31–36 *in* S. B. Monsen and S. G. Kitchen (eds.). Proceedings—Ecology and Management of Annual Rangelands, 18–22 May 1992, Boise ID. General Technical Report INT-GTR-313, Department of Agriculture, Forest Service, Intermountain Research Station.

PYNE, S. J., P. L. ANDREWS, AND R. D. LAVEN. 1996. Introduction to wildland fire. Second Edition. John Wiley and Sons, New York.

RUNDEL, P. W. AND A. C. GIBSON. Ecological communities and processes in a Mojave Desert ecosystem: rock valley Nevada. Cambridge University Press, Cambridge.

SCHMID, M. K. AND G. F. ROGERS. 1988. Trends in fire occurrence in the Arizona upland subdivision of the Sonoran Desert, 1955 to 1983. The Southwestern Naturalist 33:437–444.

SOKAL, R. R. AND F. J. ROHLF. 1995. Biometry. W. H. Freeman and Company, New York.

TRATZ, W. M. 1978. Postfire vegetational recovery, productivity, and herbivore utilization of a chaparral-desert ecotone. Master's thesis, California State University, Los Angeles. CA.

WHISENANT, S. G. 1990. Changing fire frequencies on Idaho's snake river plains: ecological and management implications. Pp. 4–7 *in* E. D. McArthur, E. D. Romney, E. M. Smith, and S. D. Tueller (eds.). Proceedings—Symposium on Cheatgrass Invasion, Shrub Die-off, and Other Aspects of Shrub Biology and Management, 5–7 April 1989, Las Vegas, NV. General Technical Report INT-276, Department of Agriculture, Forest Service, Intermountain Research Station.

WRIGHT, H. E. AND A. W. BAILEY. 1982. Fire Ecology, United States and Canada. Wiley, New York.